UNCLASSIFIED

AD NUMBER	
AD383521	
CLASSIFICATION CHANGES	
TO:	**UNCLASSIFIED**
FROM:	**CONFIDENTIAL**
LIMITATION CHANGES	
TO: **Approved for public release; distribution is unlimited.**	
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; AUG 1967. Other requests shall be referred to Army Missile Command, Attn: Research and Development Directorate, Redstone Arsenal, AL 35809. This document contains export-controlled technical data.**	
AUTHORITY	
USAMICOM ltr dtd 1 Feb 1974 USAMICOM ltr dtd 1 Feb 1974	

THIS PAGE IS UNCLASSIFIED

GENERAL DECLASSIFICATION SCHEDULE

IN ACCORDANCE WITH

DOD 5200.1-R & EXECUTIVE ORDER 11652

THIS DOCUMENT IS:

CLASSIFIED BY ____________________

Subject to General Declassification Schedule of Executive Order 11652-Automatically Downgraded at 2 Years Intervals- DECLASSIFIED ON DECEMBER 31,

BY

Defense Documentation Center
Defense Supply Agency
Cameron Station
Alexandria, Virginia 22314

SECURITY MARKING

The classified or limited status of this report applies to each page, unless otherwise marked. Separate page printouts MUST be marked accordingly.

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 AND 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

CONFIDENTIAL

COPY [redacted]	A. D.

AD383521

Technical Report S-144

BALLISTIC SCALE-UP OF NF PROPELLANTS
IV. EVALUATION OF NF PROPELLANTS IN A 6-INCH MOTOR(U)

by

S. E. Anderson

August 1967

U. S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

Contracts
DA-01-021 AMC-13864(Z)
DAAH01-67-C-0947

ROHM AND HAAS COMPANY
REDSTONE RESEARCH LABORATORIES
HUNTSVILLE, ALABAMA 35807

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

DISTRIBUTION LIMITED
SEE INSIDE FRONT COVER

CONFIDENTIAL

DISTRIBUTION LIMITATION

Initial distribution of this report has been made in accordance with contractual agreements and approved supplements received from our Contracting Officer. Qualified users may obtain this report from the Defense Documentation Center, Cameron Station, Building 5, Alexandria, Virginia 22314.

In addition to security requirements which must be met, this document is subject to special export controls, and each transmittal to foreign governments or foreign nationals may be made only with prior approval of:

Department of Army
Headquarters, U. S. Army Missile Command
Redstone Arsenal, Alabama 35809

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DISPOSITION INSTRUCTIONS

When this report is no longer needed, Department of the Army organizations will destroy it in accordance with the procedures given in AR 380-5. Navy and Air Force elements will destroy it in accordance with applicable directions. Department of Defense contractors will destroy the report according to the requirements of the Industrial Security Manual for Safeguarding Classified Information. All others will return the report to:

Department of Army
Headquarters, U. S. Army Missile Command
Redstone Arsenal, Alabama 35809
ATTN: AMSMI-IYC

DOWNGRADED AT 3 YEAR INTERVALS:
DECLASSIFIED AFTER 12 YEARS.

CONFIDENTIAL

August 1967

Technical Report S-144

BALLISTIC SCALE-UP OF NF PROPELLANTS
IV. EVALUATION OF NF PROPELLANTS IN A 6-INCH MOTOR(U)

by

S. E. Anderson

U. S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

Contracts
DA-01-021 AMC-13864(Z)
DAAH01-67-C-0947

Distribution Limited

[illegible]

In [illegible] be met, this
do[illegible] and each
trans[illegible] nationals may
be made only [illegible] U.S. Army Missile Comd.
Redstone Arsenal, Ala.

ROHM AND HAAS COMPANY
REDSTONE RESEARCH LABORATORIES
HUNTSVILLE, ALABAMA 35807

CONFIDENTIAL

ABSTRACT

Twelve 6 × 18-inch Application Motors were cast from a single 300-lbm batch of RH-SE-103af propellant and used to evaluate the capabilities of NF propellants under tactical environments. Motors were fired at -35°F, +77°F, and +135°F to establish baselines for comparison with those subjected to temperature extremes. Motors were fired successfully at -35°F after 30 days at -35°F, at +135°F after 34 days at +135°F, at +77°F after 3, 5, and 7 cycles between +135°F and -35°F, and at +77°F after 30 cycles between +135°F and +77°F. No defects of any kind were found in visual and radiographic inspections of the motors, and no aberrations in the pressure- and thrust-time curves were observed. Two motors are in ambient-temperature storage in an Army igloo; one will be fired after one year and the other will remain in storage indefinitely.

The only problems which were found in this work were (1) marginal thermal stability at +135°F and (2) a slight decrease in specific impulse with time (less than 1%). The thermal stability problem has been solved in later work, but there has been no satisfactory explanation for the decrease in specific impulse.

The interim liner used in these twelve motors was NL-10, a modification of one used in earlier tests with the same propellant. The limited processing life and inadequate storage life of this material have led to the development of lacquers based on acrylic polymers for future use.

Tests of nozzles insulated with standard 42-RPD showed that the NF propellant, in spite of its higher combustion temperature, does not require more insulation than standard plastisol nitrocellulose composite propellant.

FOREWORD

The work described in this report was performed under Contracts DA-01-021 AMC-13864(Z) and DAAH01-67-C-0947 for exploratory development of solid propulsion technology for missiles and rockets under the cognizance of the Propulsion Systems Engineering Branch, Propulsion Laboratory, Research and Development Directorate, U. S. Army Missile Command.

CONTENTS

Section I. (C) INTRODUCTION (U)

(U) Over the past several years, the formulation and scale-up of propellants based on NF binders has been a primary effort of these Laboratories. Extensive efforts in propellant research, development of processes for NF materials, liner development, and ballistic evaluation of NF propellants have been reported (1, 2, 3, 4, 5, 6, 7, 8, 9).[1] Although an 80-lbm ballistic test motor containing NF propellant was fired in November 1965, further scale-up of propellant processing and evaluation was to be done in multiple smaller-scale motors rather than one large motor. This philosophy led to the design of a 20-lbm test motor having a diameter of 6 inches, a length of 18 inches and a coned-cylindrical grain (10, 11). This motor was designated the 6CC18.

(C) This "Application Motor" had characteristics typical of Army artillery weapons (Figure 1). For example, its volumetric loading fraction lay between that of the Honest John (operational) and the MRRS (conceptual) propulsion units (Table I). This design would allow a realistic assessment of the capabilities of NF propellants for tactical rocket applications.

Table I. (C) Comparison of Application Motor Characteristics with Those of Other Army Rockets (U)

Characteristic	Honest John	Application Motor	MRRS
Volumetric Loading	0.53	0.67	0.84
Length/Diameter Ratio	7	3	5
Web/Diameter Ratio	0.11	0.24	0.32

(U) To accomplish one phase of the scale-up program for 1966 twelve 6CC18 motors were cast from a 300 lbm batch of RH-SE-103 propellant. The preparation, production, environmental treatment, testing, and evaluation of these motors is the subject of this report.

[1] Numbers in parentheses identify references at the end of the report.

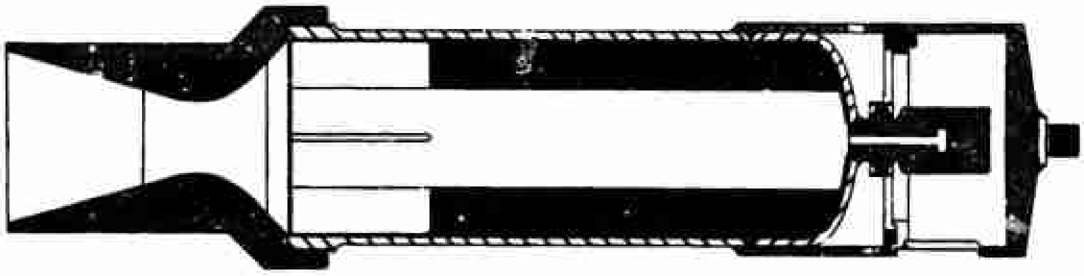


FIGURE 1. (U) CHARACTERISTICS OF 6CC18 APPLICATION MOTOR.

Parameter	Value
Grain Length (in.)	18.0
Grain O.D. (in.)	6.0
Grain I.D. (in.)	3.0
Web (in.)	1.5
Nozzle Throat Diameter, in.	1.80
Nozzle Exit Diameter, in.	5.37
Grain Weight, lbm.	20.5

Section II. (C) CHARACTERISTICS OF RH-SE-103 PROPELLANT (U)

(C) Propellants based on NFPA and TVOPA have a wide latitude in ballistic and mechanical properties. The propellant formulation used in the scale-up program contained, in addition to the binder, ammonium perchlorate and aluminum (Table II).

Table II. (C) Formulation of RH-SE-103 Propellant (U)

Component	Function	Wt. %
NFPA/AA Copolymer[a]	Binder	13
TVOPA	Plasticizer	26
Ammonium perchlorate	Oxidizer	46
Aluminum	Fuel	15
Unox® [b]-221 (added)	Crosslinker	2

[a] Acronyms are defined in the Glossary.
[b] Trademark of Union Carbide Corporation, New York, N.Y.

(C) RH-SE-103 is near the optimum point for maximum specific impulse with these ingredients. The calculated specific impulse (I°_{sps}) with all inert ingredients considered is 268.8 lbf-sec/lbm. Impulse efficiencies in 2-inch motors were generally 95% or greater. The density of the propellant is 0.065 lbm/in^3.

(C) The burning rate of the scale-up propellant with 55μ ammonium perchlorate (af grind) was 1.1 in/sec at 1000 psia, and the pressure exponent was 0.6 (Figure 2). With other oxidizer particle sizes, burning rates of 0.7 to 1.9 in/sec at 1000 psia have been obtained (6). The temperature sensitivity of pressure (π_K) measured in 2-inch motors was 0.13%/°F.

(U) The mechanical properties of propellants are functions of the rate of strain imposed during testing and also of the temperature, so the true capabilities of a propellant can only be determined by extensive characterization. The suitability of the propellant for a given application can then be determined by analysis of the grain geometry and the required environmental conditions. The properties of RH-SE-103af are in a useful range (Table III), and calculations showed that the propellant should easily withstand storage and firing in the 6CC18 at temperatures from -35°F to +135°F (11).

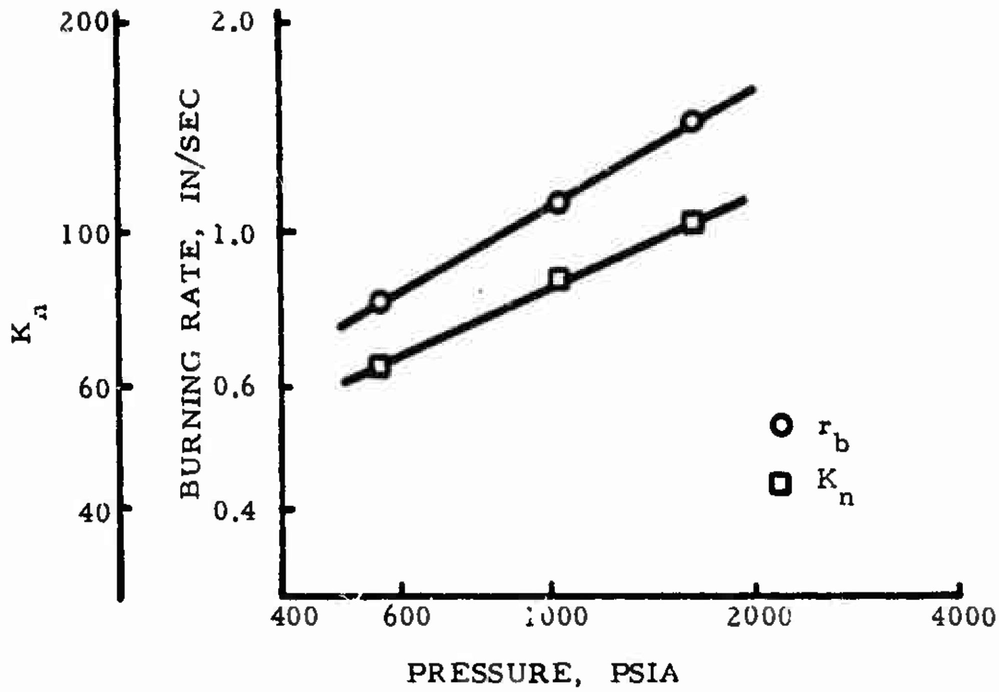


FIGURE 2. (U) BURNING RATE-PRESSURE RELATIONSHIP OF RH-SE-103af (BATCH 1120).

Table III. (U) Mechanical Properties of RH-SE-103af-Batch 1120			
	Temperature (°F)		
Property	-40	+77	+140
Maximum engineering stress, psi	437	51	32
Strain at max. stress, in/in	12	26	24

Section III. (C) PREPARATION AND PRODUCTION OF TWELVE 6CC18 MOTORS (U)

1. (C) Limitations on Liner Cure Time (U)

(U) The liner developed for use with NF propellants was formulated from polyester resins and ground asbestos. Good propellant bonding was obtained only when propellant was cast on uncured liner material. This fact required that there be careful scheduling between lining the motor cases and the propellant casting.

(C) The liner processing conditions for four 6CC18 motors produced to check the procedures included holding the lined cases at a temperature no higher than +77°F for no longer than 24 hours before casting. Bonding was good in all four motors. However, when a fifth motor was prepared and cast according to this established procedure, the propellant adjacent to the liner, although bonded, was weaker than the propellant nearer the central core. Follow-up work demonstrated that the permissible liner holding time had decreased from 24 hours to less than 6 hours. The change was associated with a minor change in propellant formulation involving the elimination of a curing catalyst, ferric acetylacetonate (Table IV).

Table IV. (C) Comparison of Original and Production NF Prototype Propellants (U)

	Weight Per Cent	
Ingredient	Original	Production
NFPA	12.35	12.35
Acrylic acid	0.65	0.65
TVOPA	26	26
Ammonium perchlorate	46	46
Aluminum	15	15
Unox-221 (added)	1.51	1.81
FeAA (added)	0.075	---

(U) Extensive research into the problem was conducted to determine the process limits on NL-1 with the new binder, to evaluate the 42-RPD®[2] phenolic/asbestos backup liner more extensively as a possible replacement, and to explore straightforward, minor modifications to NL-1 to improve processability (9). Five 6CC18 application motors were made and several lined cases were subjected to casting conditions to support the research effort. The results are summarized as follows: (1) reliable bonding to NL-1 could be obtained with a holding time of 6 hours or less, but vacuum casting of propellants on this uncured material was not possible because the liner bubbled extensively at 100 mm Hg.; (2) the processing of 42-RPD in motors still required a significant amount of development which would take more time than was available; and (3) reducing the NL-1 liner curing catalyst by 50% and adding 1% of the propellant crosslinker increased the permissible processing life back to 24 hours, and tests under vacuum showed little or no bubbling down to 25 mm Hg. The modified liner NL-10 (Table V) was used in the twelve-motor batch.

Table V. (U) Formulations of NL-10 and NL-1

	Wt. %	
Ingredient	NL-10	NL-1
Paraplex®[a] P-43	35	35
Paraplex P-13	35	35
7TF-1 Asbestos[b]	30	30
Lupersol®[c]-DDM (added)	0.5	1.0
Unox-221 (added)	1.0	--

[a] Trademark of Rohm and Haas Company, Philadelphia, Pa.
[b] Johns-Manville, New York, N. Y.
[c] Trademark of Wallace & Tiernan, Inc., Buffalo, N. Y.

[2] Trademark of Raybestos-Manhattan, Manheim, Pa.

2. (U) Production of Twelve 6CC18 Application Motors

Because the processing life of the liner was important, each processing step was scheduled carefully to avoid casting propellant on over- or under-cured liner. The holding time of the lined motors was set at 19±2 hours at +77°F and the casting vacuum was set at 75±25 mm Hg. These two conditions were fixed to assure adequate bonding with little or no bubbling of the liner.

Lining of the motors began 19 hours before the anticipated start of casting. Because casting was expected to take 30 minutes per motor, the motors were lined 30 minutes apart. With one exception, all motors were lined with freshly-mixed NL-10. Motor No. 2 was lined with the same material used in Motor No. 1. Bond-tensile specimens were made from each batch of NL-10 and these specimens were kept with the motors: half were cast at the beginning of casting and the rest at the end. The motors were cast with propellant batch 1120 on October 18, 1966.

Casting began on schedule and proceeded slightly faster than anticipated. As a result, the first motors were held exactly 19 hours before casting, and the last motors were held $17\frac{1}{2}$ hours. No liner bubbles were seen in any motor during casting. The motors were cured at 140°F for 40 hours and allowed to cool before the mandrels were removed.

Section IV. (U) INSPECTION OF APPLICATION MOTORS

Visual and radiographic inspections verified that all motors were of excellent quality. There were no bubbles, cracks, voids, or case-bond failures. The propellant was well cured. The results of the bond-tensile tests also indicated that bonding was as good as could be obtained, with breaks occurring deep in the propellant charge in every case (Table VI).

Table VI. (U) Results of Bond-Tensile Specimens Cast From Batch 1120

Liner Mix	Motor No.	Pull Strength[a] (psi)
1	1	40
1	2	40
2	3	41
3	4	37
4	5	44
5	6	48
6	7	45
7	8	39
8	9	50
9	10	48
10	11	45
11	12	48
Steel Controls		35[b]

[a] Average of 4 specimens except as noted. All NL-10 samples showed cohesive propellant breaks.
[b] Average of 3 specimens. Breaks were cohesive propellant but near interface.

Section V. (C) TESTING OF APPLICATION MOTORS (U)

1. (U) Test Plan

Twelve 20-lbm motors represented the largest single sample of NF propellant yet produced. A plan was set up to provide the maximum amount of information on the capability of NF propellant to perform properly and withstand storage and cycling at extreme environment conditions without overtesting to the extent that a valuable motor was lost. The Intermediate Temperature Range specified in AR 705-15, C-1 was used as a guide, and -35°F and +135°F were chosen as temperature extremes. To provide the data for an assessment of propellant capability under tactical conditions, the following kinds of tests were selected:

1. Storage and firing at -35°F
2. Storage and firing at +135°F
3. Cycling between +135°F and -35°F, and +135°F and +77°F
4. Storage at ambient conditions in an Army igloo.

The test plan was designed so that six motors would be fired at +77, three at -35, and three at +135 (Table VII). The results would permit an evaluation of the reproducibility of ballistic parameters, confirmation that mechanical properties were adequate for low and high temperature firings, assessment of the quality of liner-propellant bond, and assessment of the thermal stability problem.

Table VII. (U) Test Plan for 6CC18 Motors

Test No.	Number of Motors	Environmental Treatment (Temp. in °F)	Duration	Firing Conditions (°F)
1	2	Igloo storage	1 year minimum	+135/-35
2	3	+135/-35 cycling	Minimum of 3 cycles	+77
3	1	+135/+77 cycling	Up to 30 cycles	+77
4	1	-35 storage	30 days	-35
5	1	+135 storage	Up to 60 days	+135
6	2	+77 conditioning	1 day	+77
7	1	+135 conditioning	1 day	+135
8	1	-35 conditioning	1 day	-35

2. (C) Results of Baseline Tests (U)

(U) Four motors were fired initially at temperatures of +77°F, -35°F, and +135°F (Test Nos. 6, 7, 8) to establish baseline data and for comparison with data from motors made during the check-out period. The baseline numbers were used to evaluate the effects of cycling and conditioning under extreme environments on the other motors from batch 1120.

(C) The ballistic data from the +77°F firings agreed well with that from earlier tests. The average pressure $\overline{P}_b$ was about 1000 psia and the burning rate 1.1 in/sec (Table VIII). The standard deliverable specific impulse (I_{sps}) for batch 1120 averaged 259.9 lbf-sec/lbm. Pressure-time traces were smooth and consistent with the theoretical surface-time relationship (Figure 3). Since all traces had essentially the same characteristics they are not presented in this report.

Table VIII. (C) Comparison of Baseline Firings at +77°F with Earlier Check-Out Firings (U)

A. Pressure Data

Batch No.	Round No.	K_n	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$P_{max}/\overline{P}_b$	$C_D \times 10^3$ (lbm/lbf-sec)	c* (ft/sec)
1046	6233	74.8	938	1.18	1.09	6.0	5350
1046	6234	74.8	959	1.22	1.10	6.0	5370
1117	7545	80.5	829	0.98	1.12	6.1	5257
1020	7664	86.3	1011	1.11	1.10	6.1	5300
1120	7665	85.5	1012	1.09	1.09	6.0	5298

B. Thrust Data

Batch No.	Round No.	ϵ	$\overline{P}_a$ (psia)	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
1046	6233	5.4	916	251.3	260.2
1046	6234	14.0	937	250.2	259.1
1117	7545	9.0	806	247.9	256.7
1120	7664	9.1	981	256.4	260.6
1120	7665	8.8	979	255.3	259.4

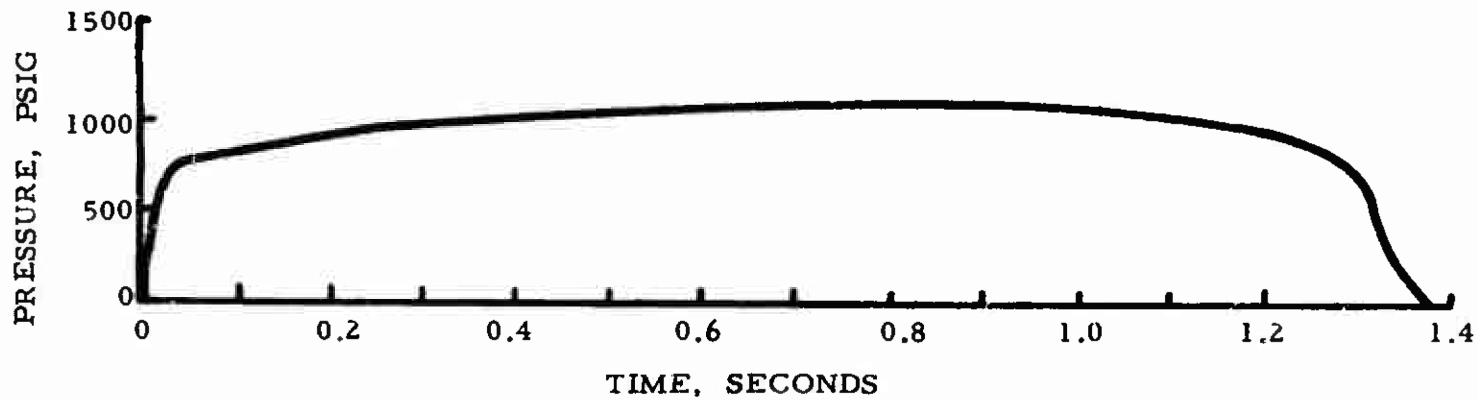


FIGURE 3. (U) REPRESENTATIVE PRESSURE-TIME RECORD FROM +77°F TEST OF RH-SE-103af PROPELLANT IN 6CC18 ROUND 7664.

(C) There was only one baseline firing at the temperature extremes but agreement between motors from batch 1120 and those from batch 1048 was good (Table IX). The effect of temperature on motor performance was the same as had been demonstrated in 2-inch firings and the temperature sensitivity of pressure at a constant K_n (π_K) was 0.13%/°F (Fig. 4).

Table IX. (C) Comparison of Baseline Tests at Temperature Extremes with Earlier Firings (U)

A. Tests at -35°F

1. Pressure Data

Batch No.	Round No.	K_n	$\bar{P}_b$ (psia)	$\bar{r}_b$ (in/sec)	$P_{max}/\bar{P}_b$	$C_D \times 10^3$ (lbm/lbf-sec)	c* (ft/sec)
1048	6639	87.0	768	0.97	1.12	6.08	5240
1120	7666	85.3	851	0.94	1.10	6.12	5257

2. Thrust Data

Batch No.	Round No.	ϵ	$\bar{P}_a$ (psia)	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
1048	6639	9.04	749	244.9	255.9
1120	7666	8.82	833	249.7	257.7

B. Tests at +135°F

1. Pressure Data

Batch No.	Round No.	K_n	$\bar{P}_b$ (psia)	$\bar{r}_b$ (in/sec)	$P_{max}/\bar{P}_b$	$C_D \times 10^3$ (lbm/lbf-sec)	c* (ft/sec)
1048	6638	87.0	955	1.20	1.08	6.08	5219
1120	7667	84.1	1097	1.26	1.13	6.04	5325

Table IX. (Cont'd) (C) Comparison of Baseline Tests at Temperature Extremes with Earlier Firings (U)

B. Tests at +135°F

2. Thrust Data

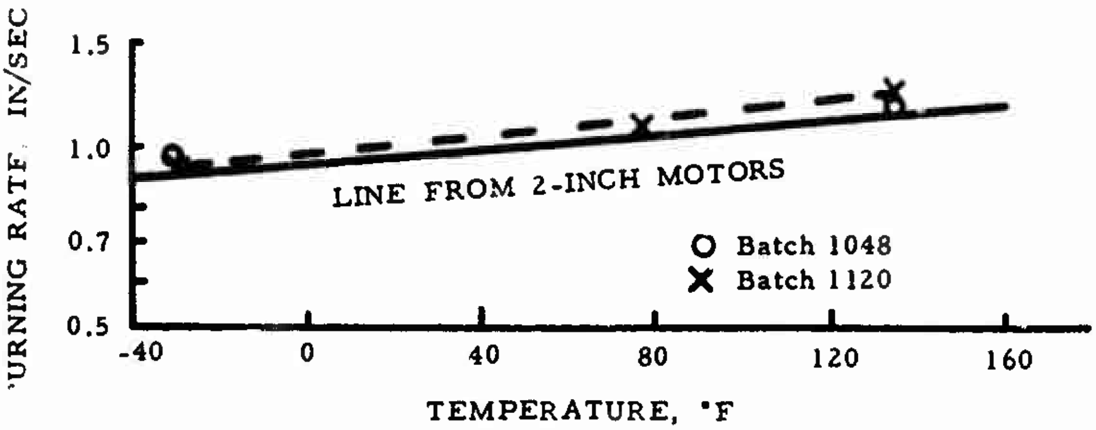
Batch No.	Round No.	ϵ	$\overline{P}_a$ (psia)	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
1048	6638	9.04	924	254.1	259.8
1120	7667	8.64	1051	257.4	260.4

3. (C) Results of Cycling Tests (U)

Three motors were cycled between +135°F and -35°F (Test No. 2) using a schedule that allowed equilibration of temperature and strain at the hot and cold conditions (Table X). No cracks, voids, or case-bond failures were found in either visual or X-ray inspections. Firings after 3, 5, and 7 cycles were successful, but a decrease in specific impulse (I_{sps}) was noted (Table XI). Burning rates and pressures also decreased, but most of this change resulted from enlargement of the nozzle throat diameter and subsequent decrease in K_n with number of cycles. The firing traces showed no aberrations such as might occur from cracks or case-bond failures.

Table X. (U) Cycling Schedule for 6CC18 Application Motors
Five days at -35°F
One day at +77°F (X-ray inspection)
Two days at +135°F
One day at +77°F (visual inspection)

One motor was subjected to a cycle which simulated storage of a motor in a tropical climate (Test No. 3). Each morning the motor was placed at +135°F, and each evening the motor was removed to +77°F. Thirty of these cycles produced no change in the appearance or integrity of the motor, and the firing was normal. Again, a slight decrease in specific impulse (I_{sps}) was the major change (Table XII).



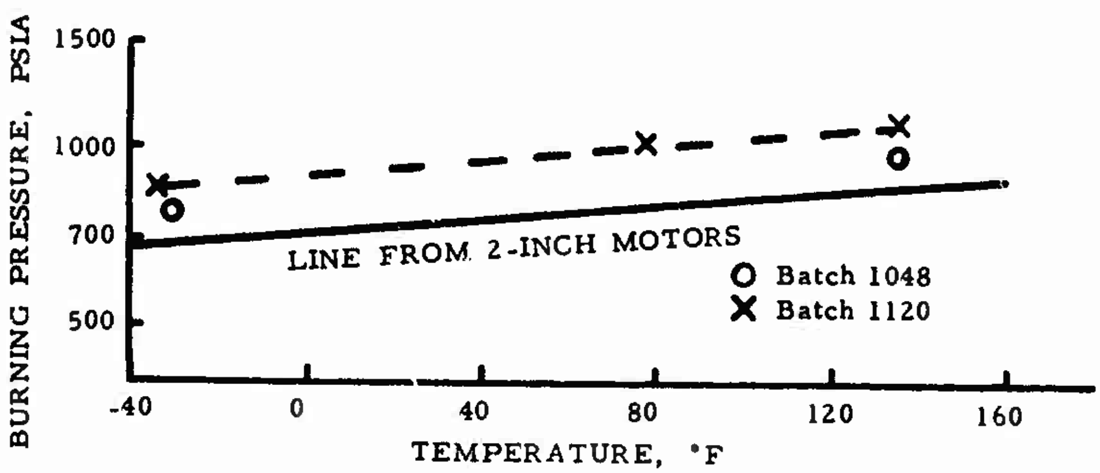


FIGURE 4. (U) EFFECT OF TEMPERATURE ON PRESSURE AND BURNING RATE IN 6CC18 APPLICATION MOTORS.

Table XI. (C) Comparison of Data from Cycled Motors with Average of Baseline Firings at +77°F (U)

A. Pressure Data

No. Cycles	Round No.	K_n	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$\frac{P_{max}}{\overline{P}_b}$	$C_D \times 10^3$ (lbm/lbf-sec)	c* (ft/sec)
Baseline	a	85.9	1012	1.10	1.10	6.1	5299
3	7832	85.5	986	1.08	1.10	6.1	5254
5	8008	84.9	955	1.04	1.12	6.1	5230
7	8228	84.3	925	1.01	1.11	6.1	5266

B. Thrust Data

No. Cycles	Round No.	ϵ	$\overline{P}_a$ (psia)	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
Baseline	a	8.9	980	255.9	259.9
3	7832	8.8	961	253.3	258.1
5	8008	8.8	935	252.7	258.1
7	8228	8.7	904	251.9	258.0

[a] Values are average of Round No. 7664 and 7665.

Table XII. (C) Comparison of Data from Motor Cycled Between +135°F and +77°F with Average of Baseline Firings (U)

A. Pressure Data

No. Cycles	Round No.	K_n	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$\frac{P_{max}}{\overline{P}_b}$	$C_D \times 10^3$ (lbm/lbf-sec)	c* (ft/sec)
Baseline	a	85.9	1012	1.10	1.10	6.1	5299
30	7911	84.9	979	1.07	1.1	6.0	5275

B. Thrust Data

No. Cycles	Round No.	ϵ	$\overline{P}_a$ (psia)	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
Baseline	a	8.9	980	255.9	259.9
30	7911	8.8	957	252.5	257.4

[a] Values are average of Round No. 7664 and 7665.

4. (C) Effect of Storage at -35°F (U)

Storage at low temperatures for long periods sometimes induces crystallization in polymers. Although this was not expected with the NFPA/TVOPA system, constant-temperature storage at -35°F for 30 days was included in the test plan (Test No. 4). If crystallization were a problem, this storage time should have been sufficient to allow it to occur. The firing at -35°F showed no evidence of cracking or any other failure which would be caused by crystallization. The motor was stored without a nozzle and was prepared for firing while cold. This allowed frost to form on the grain surface and caused an ignition delay, but the data still compared favorably with the baseline at -35°F (Table XIII). The slow ignition resulted in a longer tailoff than was normal, and this probably accounted for part of the decrease in specific impulse.

Table XIII. (C) Comparison of Data from Motor Stored 30 Days at -35°F with Baseline Firing at -35°F (U)

A. Pressure Data

Storage Time at -35°F (days)	Round No.	K_n	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$\frac{P_{max}}{\overline{P}_b}$	$C_D \times 10^3$ (lbm/lbf-sec)	c* (ft/sec)
0	7666	85.3	851	0.94	1.10	6.12	5257
30	7833	84.9	781	0.90	1.18	6.10	5220

B. Thrust Data

Storage Time at -35°F (days)	Round No.	ϵ	$\overline{P}_a$ (psia)	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
0	7666	8.82	833	249.7	257.7
30	7833	8.78	746	245.0	255.8

5. (C) Storage at +135°F (U)

(C) One of the most persistent problems with NF propellants has been fissuring during storage at moderate temperatures. Failures occur as a result of gas evolution from the slow decomposition of the NF ingredients. Double-base and CMDB

as fissuring is concerned. For example, if the temperature is decreased from 135°F to 130°F, an application motor should never fissure (Table XV).

Table XV. (U) Effect of Temperature on Time-to-Fissure in Application Motor

Temperature (°F)	Calculated Time-to-Fissure (days)
130	∞(no fissure)
135	125
140	78

(U) Modest increases in the tensile strength of the propellant could increase the critical temperature (temperature below which fissuring does not occur) for the application motor to over 140°F. Propellant which is 50% stronger than that from batch 1120 can now be made using a copolymer made by a modified process.

6. (U) Ambient-Temperature (Igloo) Storage

Two motors were stored in an igloo in the Army explosives storage area at Redstone Arsenal. One motor has been withdrawn and inspected each month and no changes have been observed in propellant integrity. The test has been in progress for 10 months. One motor will be fired after one year's storage and the second stored indefinitely. These results will be reported in the Laboratory quarterly reports.

7. (U) Test of Insulation in Application Motor

Because the flame temperature of RH-SE-103 is about 700°K higher than that of most state-of-the-art propellants and the combustion gases contain a large amount of HF, there was concern that the erosion and chemical action of these gases on insulation would be especially severe. Two lightweight aluminum nozzles were prepared with 42-RPD insulation in the converging and diverging areas of the nozzle. One was tested with RH-SE-103af, and the other with an aluminized plastisol-nitrocellulose-composite propellant (RH-P-112ci[3]). There was no difference in the amount of erosion in the two nozzles.

[3]Unit 1030, CPIA/M2 Revised Edition Solid Propellant Manual.

Section VI. (C) DISCUSSION OF RESULTS (U)

(U) The only significant problems encountered in the program were the small, but consistent, decreases in specific impulse with time, the lack of storage stability at moderately-elevated temperatures, and the marginal processing of the liner. The propellant behaved as predicted at all temperatures and ballistic properties were reproducible.

(C) The reason for the decrease in specific impulse with time is not obvious, but it could be caused, in part, by loss of TVOPA; however, well-sealed 2-inch motors stored at ambient temperature have shown a similar decrease in energy. TVOPA loss from such motors is not likely. Another hypothesis can be formulated from the fact that slow decomposition of the NF ingredients is known to occur with HF as a product. If the HF reacted with the aluminum, then part of the fuel as well as part of the high-energy ingredients could be lost. Additional research on this problem is in progress.

(U) With the progress of work in improving thermal stability, 6CC18 application motors which would never fissure at +135°F could now be made. This work also will make possible predictions of the useful life of any size motor under any extreme environment (13).

(U) The liner used in this phase of the NF program was adequate for the purpose, but could never be used on a production basis. Not only would the processing life create an untenable scheduling situation, but separation of the liner-to-steel interface has been observed in test specimens after elevated-temperature storage. No such problems occurred in any Application Motors, but new case-bonding lacquers having no known processing limitations and much improved storage capability have been developed. The most promising of these are made from terpolymers of methyl acrylate, methyl methacrylate, and acrylic acid, and can be applied by spraying or dipping in ethyl acetate solution (9).

Section VII. (U) CONCLUSIONS

Scale-up of NF propellants to this 300-lbm batch represents a significant milestone and a large step toward the successful utilization of NF propellants in actual rocket motors. In all tests in this program, RH-SE-103 propellant performed satisfactorily thus demonstrating its potential usefulness in Army missiles. The good energy and density of the propellant was again demonstrated. The reproducibility of ballistics and mechanical properties, and the predictability of the propellant show that it is ready for application and additional scale-up whenever desired.

PRECEDING PAGE BLANK-NOT FILMED

REFERENCES

1. Baldwin, M. G., Rohm and Haas Co., "NFPA-TVOPA Propellants(U)," Bull. 21st Interagency Solid Propulsion Meeting, I, 283 (1965), CPIA Publ. No. 71 (Confidential).

2. Parrott, J. W., Rohm and Haas Co., "Scale-Up of High Energy Propellants(U)," Bull. ICRPG/AIAA Solid Propulsion Conf., I, 33 (1966), CPIA Publ. No. 111 (Confidential).

3. Rohm and Haas Co., Huntsville, Alabama, PROCESS DEVELOPMENT OF A BINDER CONSISTING OF NFPA COPOLYMER AND THE PLASTICIZER, TVOPA(U), B. K. Nipp, 20 Oct. 1966, Report S-107, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contracts DA-01-021 AMC-11536(Z) and DA-01-021 AMC-13864(Z) (Confidential. AD-376 467.

4. Rohm and Haas Co., Huntsville, Alabama, PRODUCTION OF NF CHEMICALS FOR ADVANCED RESEARCH PROJECTS AGENCY(U), J. W. Parrott, 21 September 1966, Report S-119, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contract DA-01-021 ORD-11909(Z) (Confidential). AD-375 687.

6. Rohm and Haas Co., Huntsville, Alabama, BALLISTIC CHARACTERISTICS OF NF PROPELLANTS(U), S. E. Anderson and B. L. Thompson, 5 Oct. 1965, Report S-85, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contracts DA-01-021 AMC-11536(Z) and DA-01-021 AMC 11608(Z). (Confidential. AD-366 080.

7. Rohm and Haas Co., Huntsville, Alabama, BALLISTIC SCALE-UP OF NF PROPELLANTS I. 80-LBM MOTOR DEMONSTRATION FIRING(U), S. E. Anderson, 17 March 1966, Report S-94, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contracts DA-01-021 AMC-11536(Z) and DA-01-021 AMC-11608(Z) (Confidential). AD-370 635.

8. Rohm and Haas Co., Huntsville, Alabama, THE EXPLOSIVE CHARACTERISTICS OF NF COMPOUNDS AND PROPELLANTS(U), T. H. Pratt, 8 Oct. 1965, Report S-79, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contracts DA-01-021 ORD-11878(Z), DA-01-021 ORD-11909(Z), and DA-01-021 ORD-11536(Z) (Confidential). AD-366 209.

9. Rohm and Haas Co., Huntsville, Alabama, BALLISTIC SCALE-UP OF NF PROPELLANTS III. LINER DEVELOPMENT(U), S. E. Anderson and B. L. Thompson, July 1967, Report S-142, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contracts DA-01-021 AMC-13864(Z) and DAAH01-67-C-0947 (Unclassified).

10. Rohm and Haas Co., Huntsville, Alabama, APPLICATION OF NF PROPELLANTS—A STUDY REPORT(U), S. E. Anderson, 25 May 1965, Report S-62, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contracts DA-01-021 AMC-11536(Z) and DA-01-021 AMC-11608(Z) (Confidential). AD-360 789.

11. Rohm and Haas Co., Huntsville, Alabama, BALLISTIC SCALE-UP OF NF PROPELLANTS II. EVALUATION OF NF PROPELLANTS IN A 6-INCH MOTOR (INTERIM REPORT)(U), S. E. Anderson, 21 April 1967, Report S-125, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contract DA-01-021 AMC-13864(Z) (Confidential). AD-380 551.

12. S-126, Allen, E., in preparation.

13. S-140, Willoughby, in preparation.

(C) GLOSSARY (U)

(U) Symbols

c^*	Characteristic exhaust velocity, ft/sec
C_D	Mass discharge coefficient, lbm/lbf-sec
I°_{sps}	Standard theoretical propellant specific impulse, lbf-sec/lbm
I_{spd}	Measured (delivered) propellant specific impulse, lbf-sec/lbm
I_{sps}	Standard deliverable propellant specific impulse, lbf-sec/lbm
K_n	Burning surface to throat area ratio, dimensionless
$\overline{P}_a$	Action time average chamber pressure, psia.
$\overline{P}_b$	Burning time average chamber pressure, psia.
P_{max}	Maximum chamber pressure, psia
$\overline{r}_b$	Linear burning rate of propellant, in/sec.
ϵ	Nozzle area expansion ratio.
π_K	Temperature sensitivity of pressure at a given K_n.

(C) Acronyms (U)

(U) AA	Acrylic Acid
(C) NFPA	2,3-bis(difluoramino)propyl acrylate
(C) TVOPA	1,2,3-tris(1,2-bis[difluoramino]ethoxy)propane

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Rohm and Haas Company Redstone Research Laboratories Huntsville, Alabama 35807	2a. REPORT SECURITY CLASSIFICATION Confidential 2b. GROUP 4

3. REPORT TITLE

Ballistic Scale-Up of NF Propellants IV. Evaluation of NF Propellants in a 6-inch Motor

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Stanley E. Anderson

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1967	25	13

8a. CONTRACT XXXXXXXXX b. XXXXXXXXX DA-01-021-AMC-13864(Z) c. DAAH01-67-C-0947 d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report S-144 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Initial distribution of this report has been made in accord with contractual agreements. Qualified users may obtain from Defense Documentation Center.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Research and Development Directorate U. S. Army Missile Command Redstone Arsenal, Alabama 35809

13. ABSTRACT

Twelve 6 × 18-inch Application Motors were cast from a single 300-lbm batch of RH-SE-103af propellant and used to evaluate the capabilities of NF propellants under tactical environments. Motors were fired at -35°F, +77°F, and +135°F to establish baselines for comparison with those subjected to temperature extremes. Motors were fired successfully at -35°F after 30 days at -35°F, at +135°F after 34 days at +135°F, at 177°F after 3, 5, and 7 cycles between +135°F and -35°F, and at +77°F after 30 cycles between +135°F and +77°F. No defects of any kind were found in visual and radiographic inspections of the motors, and no aberrations in the pressure- and thrust-time curves were observed. Two motors are in ambient-temperature storage in an Army igloo; one will be fired after one year and the other will remain in storage indefinitely.

The only problems which were found in this work were (1) marginal thermal stability at +135°F and (2) a slight decrease in specific impulse with time (less than 1%). The thermal stability problem has been solved in later work, but there has been no satisfactory explanation for the decrease in specific impulse. (cont'd on back page)

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
NF propellant utility environmental capability thermal stability scale-up production reproducibility ballistic properties mechanical properties 6-inch test motors liners insulation cone-and-cylinder grain						

(Abstract cont'd)

The interim liner used in these twelve motors was NL-10, a modification of one used in earlier tests with the same propellant. The limited processing life and inadequate storage life of this material have led to the development of lacquers based on acrylic polymers for future use.

Tests of nozzles insulated with standard 42-RPD showed that the NF propellant, in spite of its higher combustion temperature, does not require more insulation than standard plastisol nitrocellulose composite propellant.